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Final Report

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Investigation of Cloud/Water Vapor Motion
Winds from Geostationary Satellite

Contract NAG8-892

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This report summarizes the research work accomplished on the NASA grant contract NAG8-892 during 1992. Research goals of this contract were stated in the proposal as; complete upgrades to the CIMSS wind system procedures for assigning heights and incorporating first guess information, evaluating these modifications using simulated tracer fields, adding an automated quality control system to minimize the need for manual editing, while maintaining product quality, and benchmarking the upgraded algorithm in tests with NMC and/or MSFC.

Work progressed on all these tasks and is detailed below. This work was done in collaboration with CIMSS NOAA/NESDIS scientists working on the operational winds software, so that NASA funded research can benefit NESDIS operational algorithms.

A. Comparison of Satellite Derived Wind Sets and Rawinsondes (C. Hayden, NOAA/NESDIS, C. Velden, UW)

In the early spring of 1990, a team from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) joined with the NESDIS Interactive Processing Branch and the Satellite Analysis Branch in introducing and testing at the VAS Data Utilization Center a new software system designed at CIMSS for automated cloud motion winds which retrieves the pressure altitude assignment from the CO2 slicing method. In addition, CIMSS has developed a system for objective quality control of the winds generated from tracers. This quality control includes both pressure altitude reassignment by objective assimilation with other data and objective editing (Hayden, 1991; Hayden and Velden, 1991). It is a part of the new wind generating system (referred to as the autowind/autoeditor in this proposal). Wind vectors generated during this spring 1990 demonstration were given to the NMC to investigate forecast impact. One of the highlights occurred on April 24 and 25, when the new pressure assignment method succeeded in correctly locating the altitude of thin cirrus tracers off the coast of California associated with a shortwave which would later affect the weather over the U.S. (Merrill et al. 1991). The success of this venture breathed new life into applied research for improving the vectors obtainable from satellite imagery, and one consequence was an agreement with Marshall Space Flight Center (MSFC) that they use the April test case with their vector generating software for comparison with the CIMSS system, the eventual goal being the amalgamation of better aspects of the two methods. MSFC agreed to this task, and subsequently delivered a data set to CIMSS which included vectors from visible, infrared window, and water vapor (6.7 micrometer) imagery for April 25, 00 UTC. CIMSS evaluation of these data was conducted under this contract and the results are briefly highlighted here.

The MSFC wind data were evaluated by the new auto editor quality control system. Figure 1 shows the IR and H2O winds from both CIMSS and MSFC. An obvious conclusion is that MSFC seems to have a superior technique for obtaining targets in the water vapor imagery. Certainly their density is much higher. Another conclusion from examination of the MSFC visible data set (not shown) is that CIMSS and NESDIS should be paying more attention to visible data to improve vector coverage. Finally, the CIMSS assimilation system was quite successful in blending the MSFC winds into the analysis, despite the deficiencies of the initial height assignment. Although an obvious bias to

the NMC forecast is enforced by the reassignment, the end result in comparison to rawinsondes shows an rms improvement over the forecast.

The new CIMSS autowind/autoeditor wind system became operational at NESDIS on February 12, 1992. The performance of the autowind/autoeditor for the first six months of operation is summarized in Table 1. Upper level CMVs show a slow bias of -1.3 m/s (reduced from about -5 m/s previously) and a rms difference of 6.1 m/s (reduced from about 8 m/s previously) with respect to rawinsonde reports.

Table 1. Cloud Motion Vector (CMV) Results after Six Months of NESDIS Operations with CO2 Autowinds; Feb-Jul 1992 statistics CMVs versus rawinsonde reports (R) and the NMC 12 hour forecast guess (G). The number of comparisons for hi and mid level winds are indicated in parentheses.

Vector RMS (m/s)	G-R	CMV-R	CMV-G
hi (1163)	6.44	6.14	5.00
mid (337)	4.89	5.28	3.47

Mean Speed (m/s)	G	CMV	R
hi	20.2	21.7	23.0
mid	15.9	12.7	14.3

Hayden, C. M. and C. S. Velden, 1991: Quality control and assimilation experiments with satellite-derived wind estimates. Preprint Volume, 9th Conference on Numerical Weather Prediction, Denver, CO. Amer. Meteor. Soc., 19-23 October.

Hayden, C. M. 1991: Research leading to operational methods for wind extraction. Proceedings of the Workshop on Wind Extraction from Operational Meteorological Satellite Data, Washington, DC, 17-19 September, Eumetsat ISBN 92-9110-007-2.

Merrill, R. T., W P. Menzel, W. Baker, J. Lynch, and E. Legg, 1991. A report on the recent demonstration of NOAA's upgraded capability to derive cloud motion satellite winds. Bull. Amer. Meteor. Soc., 72, 372-376.

B. Use of Cloud Classification Predictors for Cloud Tracer Selection in Operational Winds Algorithms (C. Moeller, CIMSS)

The utility of cloud feature characteristics as additional information to the operational automated cloud tracking wind algorithm is being investigated. This effort is aimed at improving the quality of operationally produced cloud tracked winds, while eliminating computational time spent trying to produce vectors from cloud targets which are not likely to yield good quality vectors. Automated wind vectors can be improved by limiting cloud tracer selection to tracers that are, more often than not, accurately tracked (via correlation technique) through time. A goal of this work is to base cloud tracer selection on cloud feature characteristics as well as the

usual pixel brightness and gradient thresholds. The characteristics for describing cloud tracers include cloud albedo, fraction, multilayering, height of base and top, spatial distribution and orientation, connectivity (cloud and background), and type (Garand, 1988). These cloud characteristics are being compared to cloud tracers and vectors produced by the operational cloud tracking procedure in an effort to identify the conditions under which good (and bad) quality wind vectors are produced. Those characteristics demonstrating skill in identifying good (and bad) cloud tracers will be retained; those not demonstrating skill will be removed from the algorithm to reduce computational time.

Initial efforts have focussed on the bi-spectral cloud classification method (Garand, 1988). Investigating multilayer index, cloud fraction, cloud top temperature, and cloud connectivity as predictors of tracer quality in a limited sample has revealed that better performance occurs when the cloud fraction is between .2 and .8, when there is low background connectivity, and when the multilayer index is small.

Garand, L., 1988: Automated Recognition of Oceanic Cloud Patterns. Part I: Methodology and Application to Cloud Climatology. Jour. of Clim., Vol.1, No.1, 20-39.

C. Comparison of Several Techniques for Assigning Heights to Cloud Tracers (S. Nieman, UW, P. Menzel, NOAA/NESDIS, J. Schmetz, ESOC)

In the current operational use of four geostationary satellites, satellite derived cloud motion vector (CMV) production has been troubled by inaccurate height assignment of cloud tracers, especially in thin semi-transparent clouds. At the recent Workshop on Wind Extraction from Operational Meteorological Satellite Data (Eumetsat, 1991) there was a consensus that the present techniques for height assignment needed further review and that greater commonality in techniques should be encouraged.

Presently heights are assigned by any of three techniques, when the appropriate spectral radiance measurements are available. In opaque clouds, infrared window (IRW) brightness temperatures are compared to forecast temperature profiles to infer the level of best agreement, which is taken to be the level of the cloud. In semi-transparent clouds or sub-pixel clouds, since the observed radiance contains contributions from below the cloud, this IRW technique assigns the cloud top at too low a level. Corrections for the semi-transparency of the cloud are possible with the carbon dioxide (CO₂) slicing technique (Menzel et al., 1983) where radiances from different layers of the atmosphere are ratioed to infer the correct height. A similar concept is used in the water vapor (H₂O) intercept technique (Szejwach, 1982), where the fact that radiances influenced by upper tropospheric moisture (H₂O) and IRW radiances exhibit a linear relationship as a function of cloud amount is used to extrapolate the correct height. These three techniques are being compared at CIMSS through this contract and other NESDIS supported work.

There is an added impetus to this work. The European community is sharing one of its satellites with the United States, METEOSAT-3 (M3). Understanding the relative performance of the NESDIS operational CO₂ slicing heights and the ESOC (European Satellite Operations Center) operational H₂O/IRW intercept heights is necessary for the United States to begin

production of CMVs with M3. Furthermore, GMS-5 will be supplemented with a water vapor channel so that international commonality of height assignment can move closer, if viable H2O/IRW height performance can be verified.

Evaluations to date suggest that the H2O/IRW intercept technique is a viable alternative to the CO2 slicing technique for inferring the heights of semi-transparent cloud elements (Nieman et al., 1992). On a given day the heights from the two approaches compare to within 60 to 110 mb rms; drier atmospheric conditions tend to reduce the effectiveness of the H2O/IRW intercept technique. The infrared window channel technique consistently places the semi-transparent cloud elements too low in the atmosphere by 100 mb or more; only in more opaque clouds does it perform adequately. Comparison of the heights produced operationally at NESDIS (with the CO2 slicing technique) and ESOC (with their version of the H2O/IRW intercept technique) reveal that the cloud height algorithms are approaching an international commonality. Table 2 summarizes the intercomparisons.

Table 2. Cloud Height Comparisons for CO2, H2O, and IRW Techniques Using Radiances from GOES-7 and METEOSAT-3 and -4

IRW, CO2/IRW, and H2O/IRW height assignments for cloud tracers using VAS radiances from 20 to 50N and 50 to 100W for 29-31 January 1992.

All 3 days (199 tracers)	Mean Cloud Top Pressure (hPa)	Scatter wrt Mean (hPa)	RMS Deviation (hPa)	
			wrt CO2/IRW	wrt H2O/IRW
IRW	416	102	109	141
CO2/IRW	344	87	--	85
H2O/IRW	314	65	85	--

Collocated Meteosat-3 (M-3) and GOES-7 (G-7) H2O height assignments for cloud tracers on 29-31 January 1992.

All 3 days (97 tracers)	Mean Cloud Top Pressure (hPa)	Scatter wrt Mean (hPa)	RMS Deviation (hPa) wrt G-7 H2O
G-7 H2O	285	80	--
M-3 H2O	294	89	94

Collocated CIMSS and ESOC Meteosat-4 (M-4) H2O height assignments for upper level (150-600 hPa) cloud tracers on 21 March, 27 April, 30 April 1992.

Both days (136 tracers)	Mean Cloud Top Pressure (hPa)	Scatter wrt Mean (hPa)	RMS Deviation (hPa) wrt CIMSS M-4 H2O
CIMSS M-4 H2O	272	97	--
ESOC M-4 H2O	297	100	77

Nieman, S., J. Schmetz, and W. P. Menzel, 1992: Intercomparison of Several Cloud Tracer Height Assignment Techniques. submitted to Jour. Appl. Met.

EUMETSAT, 1992: Workshop on wind extraction from operational meteorological satellite data, 17-19 September 1991. EUM P 10, ISBN 92-9110-007-2.

Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. J. Clim. Appl. Meteor., 22, 377-384.

Szejwach, G., 1982: Determination of semitransparent cirrus cloud temperatures from infrared radiances: application to METEOSAT. J. Appl. Meteor., 21, 384.

D. Inferring Winds from Time Sequences of Water Vapor Radiance Measurements (C. Velden and S. Nieman, UW, P. Menzel, NOAA/NESDIS)

Water vapor winds are intended to supplement infrared cloud drift winds in regions where there are no clouds. With the extended data coverage of METEOSAT-3, water vapor radiances of increased spatial resolution (5 km rather than the GOES-7 16 km) and enhanced signal (noise equivalent radiances of METEOSAT-3 are half those of GOES-7) are available over the eastern coast of North America and the Atlantic Ocean. Atmospheric motions have been inferred from animated hourly radiance measurements in the water vapor channel (covering 5.8 to 7.3 microns) for three months using the CIMSS autowind/autoeditor techniques. Figure 2 shows an example METEOSAT-3 water vapor winds set. The most striking feature of these wind fields are their good spatial coverage; while CMVs exist only where there are trackable cloud features, the H2O winds are estimated wherever sustained water vapor radiance gradients are measured. Comparisons with rawinsonde reports indicate very good skill at estimating mid-level flow fields. Table 3 shows the results for about 500 land-based comparisons. Since the guess is likely much worse over the oceans while the wind statistics should remain fairly constant regardless of location, these H2O winds should have positive impact in marine analysis and applications. This will be evaluated through coordinated model impact studies with NMC and ERL/AOML-HRD.

The results in Table 3 offer encouragement for determination of global mid-level atmospheric flow using the geostationary satellites available internationally for the rest of this decade. Figure 1 shows the global coverage from the current geostationary satellite configuration (INSAT excluded). GOES-7, METEOSAT-3, and METEOSAT-5 have water vapor channels (GMS-5 to be launched in 1994 will also have a water vapor channel). The density of water vapor gradient vectors is roughly 10 per 5 x 5 degree latitude-longitude box with very good horizontal coverage. Features can be tracked accurately out to about 50 degrees from satellite nadir view. Figure 3 shows the global water vapor wind coverage this would enable.

Table 3. Accumulated statistics on autowind/autoeditor M-3 H2O winds for April through June 1992 versus rawinsondes. Statistics are for 498 intercomparisons and are given in m/s. Guess refers to the six hour NMC forecast.

Speed Bias

H2O wind minus rawinsonde -1.18

model guess minus rawindsonde -1.30

Vector RMS Differences

H2O wind minus rawinsonde 6.74

model guess minus rawindsonde 5.45

De Waard, J, W. P. Menzel, and J. Schmetz, 1992: Atlantic Data Coverage with METEOSAT. BAMS